Road4FAME – Orientation Paper

Date: January 31, 2015
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Version: Final Version

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Summary

Manufacturing is no longer solely concerned with the physical production of goods. This is now but one element in a wider manufacturing value chain, which encompasses production, research, design, and service provision. The use of digital technologies throughout the manufacturing value chain plays a key role in driving the productivity growth essential to a competitive Europe.

Road4FAME is an EU-funded project that is examining industry need using four **manufacturing scenarios** with which companies may increasingly identify: 1. the manufacturing-as-a-service enterprise; 2. the virtual enterprise; 3. the high-volume/high-value production enterprise; 4. the green enterprise.

The gap between current capability in manufacturing ICT and successful performance under those scenarios is characterised by a number of **challenges,** many of which impact particularly upon small and medium-sized enterprises (SME), such as:

- a highly heterogeneous manufacturing ICT landscape and lack of interoperability
- high implementation costs
- increasing demands from customers for flexibility, customisation and track-and-trace capability.

As that gap narrows other challenges will also come to the fore, notably cybersecurity.

Road4FAME to-date findings have identified a number of research areas with potential to support companies in overcoming these challenges and strengthening their competitive position.

Key recommendations are that there is a need for research into the following topics:

a) Real-time data acquisition and analysis
b) Network-centric communication and collaboration between organisations, humans and systems across the entire value chain
c) Scalable cyber-physical system architectures for adaptive and smart manufacturing systems
d) Cross-cutting and non-functional challenges: interoperability standards, semantic mechanisms, data visualization, sociotechnical issues, training and education, as well as cybersecurity

Addressing these issues could have a real **impact** on manufacturing industry such as: reduced development and implementation costs; increased competitiveness of SMEs; substantial improvements in manufacturing efficiency, quality and flexibility; innovative business models; exploitation of market potential.

The sections of this paper cover: (1) how the term ‘manufacturing’ is currently understood; (2) the four manufacturing scenarios that form the basis of Road4FAME roadmapping work; (3) general challenges and (4) specific challenges that the recommended research would address and (5) the impact that addressing these challenges would have on the manufacturing industry. The final section (6) indicates how the conclusions and recommendations are derived from expert input and Road4FAME analysis of national and international studies and country strategies.

1. Manufacturing context and definitions[i ii iii]

Traditionally, manufacturing has been defined as the production process whereby raw materials are transformed into useful products and goods. Nowadays, although physical transformation is often at the centre of a wider manufacturing value chain, manufacturing goes beyond production, to also encompass research, design and service provision. Manufacturers are frequently using this wider value chain to generate new and additional revenues.

Exploiting solutions across the manufacturing process chain that are based on information and communications technology (ICT) is important for:

- making manufacturing more efficient
- allowing more personalized, diversified and at the same time mass-produced product portfolios
- flexible reaction to market changes.

Thus, enabling manufacturers to stay ahead of the competition ensures Europe's competitiveness.

Digital manufacturing assumes a key role for innovation and economic growth. A recent Lisbon Council policy paper recognizes the role of digital technologies and greater adoption of ICT, mostly in non-ICT sectors, in helping to drive 'the productivity growth [that] is the key to returning to a sustainable growth path in Europe' (2014) [iv].

Definitions

There are many different definitions of manufacturing. Some highlight **the systems-nature** of manufacturing, while others emphasize particular technological and/or organizational enablers that are **sources of competitive advantage**. Sometimes the term High Value Manufacturing (HVM) is used to characterise the latter.

Some recent descriptions of manufacturing illustrate the range of definitions:

> 'The new era of manufacturing will be marked by highly agile, networked enterprises that use information and analytics as skillfully as they employ talent and machinery to deliver products and services to diverse global markets' (McKinsey & Company, 2012)[v].
>
> 'The application of leading-edge technical knowledge and expertise for the creation of products, production processes and associated services, which have strong potential to bring sustainable growth and high economic value to the UK. Activities may stretch from R&D at one end to recycling at the other' (Technology Strategy Board, 2012)[vi].
>
> 'Digital Technologies such as Cyber Physical Systems, Internet of Things and Machine to Machine communication, are radically changing business and industrial processes, enabling entire new classes of products and services. ICT will decentralize production by enabling flexible, programmable and embedded forms of manufacturing, by synchronizing complex, high-end production systems, and by

creating highly innovative value chains that cut across traditional sectors and domains' (Dutch Agenda – Smart Industry, 2014)[vii].

'The world is in the midst of a paradigm shift in the 21st century – one that integrates diverse sets of ideas, products and services globally through the lens of highly complex, integrated and self-morphing resource webs… Highly talented skilled people are necessary to effectively and consistently apply cutting edge science and technology, systems thinking, smart services and processes, and supply chain excellence' (Deloitte, 2013)[viii].

The 'fourth industrial revolution'

Industry 4.0, a major initiative of the German government and industry, sees digital manufacturing as the fourth industrial revolution (following the revolutions in manufacturing successively brought about by 1) the steam engine, 2) assembly-line work, and 3) electronics and automation). It sees the fourth industrial revolution as based on the technical integration of cyber-physical systems (CPS) in production and logistics as well as the application of the Internet of Things (IOT) and services in industrial processes. Hence the Industry 4.0 definition of manufacturing includes the resulting outcomes for adding value – the business models and the subsequent services and work organisation.

2. Road4FAME manufacturing scenarios

Road4FAME has established four working scenarios as a basis for considering the future needs and requirements of manufacturing companies:

1. the Manufacturing-as-a-Service (MaaS) Enterprise
2. the Virtual Enterprise
3. the High-Volume/High-Value Production Enterprise
4. the Green Enterprise

These scenarios have been constructed in such a way as to be a) challenging and b) not yet possible, that is, they are visionary in nature. Companies that identify with a particular manufacturing scenario are likely to face similar challenges and are likely to have needs and requirements regarding manufacturing ICT in common.

Figure 1 indicates how each scenario is focused in relation to product/service orientation and system/product oriented manufacturing.

Note that the four scenarios are not alternative visions of future manufacturing but, rather, describe interesting and important manufacturing settings with which manufacturing companies are likely to increasingly identify. The four scenarios are not mutually exclusive: a manufacturing company may be able to identify with aspects of more than one scenario.

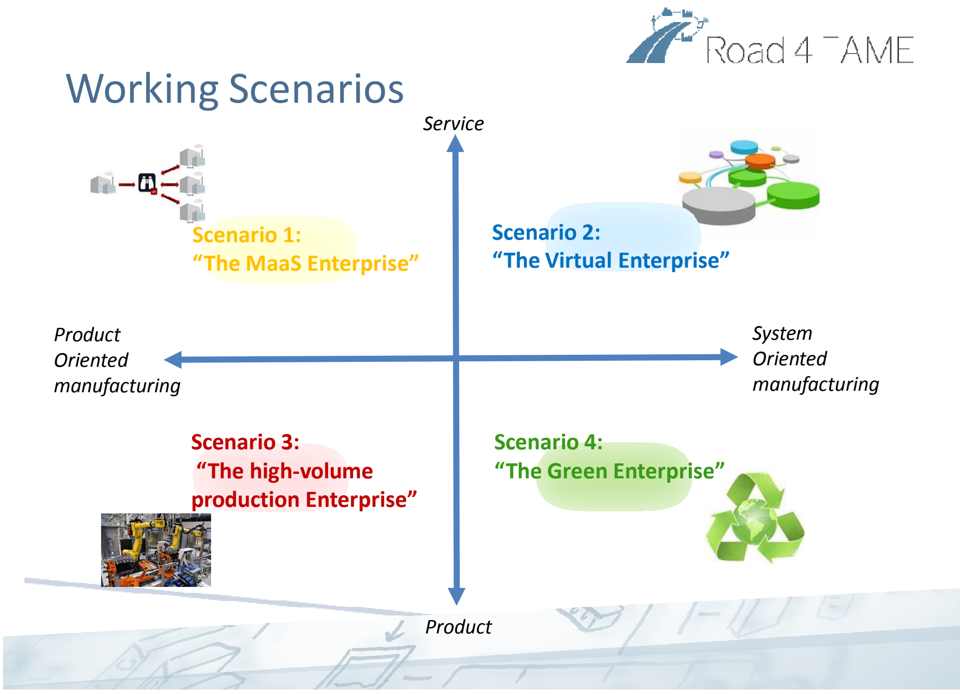

Figure1. Road4FAME manufacturing scenarios

The following provides a brief description of each scenario and outlines the challenges which each scenario entails.

Scenario 1: The Manufacturing-as-a-Service (MaaS) Enterprise

The MaaS enterprise does not market products, but offers manufacturing as a service. Unlike a traditional supplier, its manufactured goods are complex and fully customized. It frequently faces short-notice requests for high volume orders. The MaaS enterprise needs to be able to quickly reconfigure and scale up its production as well as share information rapidly with customers, i.e. integrate with other suppliers, enter into business agreements, and cooperate with the new partners in order to fulfil new orders appropriately. The range of offered services goes beyond the pure manufacturing process, extending across the value chain, for example product design, after sales support, and product maintenance.

ICT is a key asset throughout the manufacturing cycle, covering computer-aided technology (CaX) tools, engineering, prototyping, production and qualification phases to enable 'what you see is what you get' (WYSWYG). Digitization of, for example, product quality, user-characteristics and production parameters based on sensory systems will also crucial to new innovations in the production process, products and services. Digital tools are instrumental to ensure de-coupling of design and production steps. One well-known example of de-coupling is the model of outsourcing production of semiconductor chips to semiconductor foundries; another prominent example would be 3D printing. Companies using traditional processes like CNC machining are gradually adopting similar principles.

The company offers its manufacturing services globally and is strongly dependent on an efficient mechanism for providing its services. These services also depend on the design and manufacturing software (computer-aided design (CAD)/computer-aided manufacturing (CAM)) that the company and its clients use. Interoperability issues play an important role in a MaaS enterprise, as clients may use different software and the enterprise should be able to work with as many as possible to access a wider market of clients. The company's strategic plan is to be able to anticipate changes in demand from customers, maintaining the pace of technological progress in the sector and improving the company's ability to take orders ad hoc. Predicting trends in order to provide on-demand services will require the use of data mining, on a variety of data coming from many sources, such as social networks.

Scenario 2: The Virtual Enterprise

The virtual enterprise is an association of companies which acts as a production and/or innovation network. Companies co-operate as and when required in order to:

- react to market opportunities
- do research together
- develop new or improved products
- minimize the costs and risks in targeting new markets with new products

Companies will also seek to ensure the flexibility of their complex supply chain and the fast re-configurability of their production lines (e.g. through self-adaptive and modular machine tools and robots) to meet changing consumer requirements.

The virtual enterprise is established ad hoc to meet a short-term need and dissolves after the desired outputs have been achieved. The companies involved must join forces effectively in order to form what is in essence one business out of several separate ones. There are mechanisms to avoid replication of capacity. As multiple partners might have overlapping capabilities, companies need to bid internally for selection.

ICT has enabled improved, geographically distributed manufacturing processes underpinned by knowledge management systems able to cope with the entire production cycle from design to sales and service supply. The role of ICT is to enable full virtualization of resources through an interoperable platform that connects and synchronizes critical business processes along the value chain; that a) aligns priorities, b) identifies resource demand and supply, and c) exchanges information about critical product and production data in order to enable fast ad-hoc decision making.

A virtual enterprise consisting of SMEs, for example, enables them to complement each other's strengths or to attain the capacities of large enterprises. A virtual enterprise consisting of both large and small companies enables the partners to combine their strengths: the large companies bring in their capacity, while the small companies contribute their flexibility and power to innovate. In addition, the virtual enterprise enables a much broader product and service portfolio than any individual company could provide by working alone.

The Virtual Enterprise is often confined to a regional eco-system for which ICT communication and sharing provide means for networking, collaboration and integration. Companies are required to engage in regionally based operations to better and faster fulfil local demands. Examples of a nascent virtual enterprise scenario include regional manufacturing of fashion products in countries such as Italy.

Scenario 3: The High-Volume/High-Value Production Enterprise

This scenario describes a company which produces high volumes of high-value goods and increasingly faces the challenge of shorter product life-cycles. To remain competitive, it also needs to be capable of offering an increasing degree of customization, despite the high volumes produced – in other words, mass customization. The supply network in which the company is embedded is characterized by a mix of long-term and ad-hoc co-operation.

As product development, production planning and engineering, production execution and manufacturing services are converging – thanks to process digitalization and cutting-edge software tools – the product quality, the degree of customization and development speeds increase while maintaining competitive prices.

In this scenario, the level of plant automation is high, and the customization of production requires short reconfiguration cycles, as well as short ramp-up and scale-up cycles. Such cycles include tests/experimental production, fast re-programming of machines and frequent updates of information to the workers, who need to be skilled and also frequently re-trained. ICT supports and drives convergence of manufacturing execution systems (MES) and enterprise ICT systems to establish de-centralised, flexible automation architecture. Context-awareness of production facilities and moving decisions to the point of interest – that is, close to the sensor and monitoring system – are important in order to adapt production in real time to current product specifications, react to and schedule order execution appropriately, and according to ongoing customer demands.

Beyond the individual plant, a network-centric approach to production will replace linear production processes. These networks will interconnect parts, products and machines across production plants, companies and value chains at a highly granular level. This scenario accords with the German Industry 4.0 vision for networked and smart production architectures (see box on p. 4).

The digital factory is not only about more advanced sensor information and monitoring systems with high granularity levels. It is also key to drive further data aggregation and automation, together with next generation control systems. New ways of pattern recognition, data analytics and predictive modelling can even lead to fully automated facilities and to smart and automated ways to support production assistants and decision-making in any situation and context.

Whenever a company has to react to an increasingly dynamic market its workers have to swiftly acquire new knowledge. With the half-life of relevant knowledge decreasing, the rate of human knowledge acquisition threatens to become the limiting factor for companies attempting to keep pace with technological progress. Appropriate ICT support has to be provided to the human embedded in the digital factory, in the form of context-relevant information and on-the-fly knowledge provision supported by, for example, knowledge-based decision support systems or self-learning systems supported by co-operation between humans, machine and data. Examples of a high-volume/high-value manufacturing enterprise can be found in the automotive industry for example, especially on high-end cars, where differentiation is an important buying criterion for customers.

Scenario 4: The Green Enterprise

This scenario describes a company for which environmental awareness is an important part of its corporate identity. The company's goal is to go beyond a mere 'green washing' of its image and products to the introduction of environmental sustainability as a key parameter in all steps of the product life-cycle, including sourcing and recycling.

In this scenario, thanks to analysis of data from a large number of sources, real-time information about the footprint of manufacturing processes is available to steer production towards minimal environmental impact. Keeping record of the origin and history of raw materials as an additional aspect of environmental awareness is used as a marketing advantage. Buyback of products for recycling or product rental and return-to-recycle policies are strategic, increasing sustainability on sourcing and creating stronger bonds with customers.

The environmental footprint of ordered, customized products is made available to customers in the customization step, so the footprint generated along the value-chain is transparent to the customer and environmentally aware buying decisions can be made. So, to the manufacturer and the customer, the environmental footprint is available and can be taken into account as an actual decision parameter. The environmental implications of design, process, and buying decisions become completely transparent.

With a certain customer segment increasingly demanding such transparency, the competitiveness of the company increasingly depends on the degree of transparency it is able to provide and the level of environmental sustainability it can demonstrate. Thus, its capability to be ‘green’ translates into tangible economic value.

Nascent examples of a green enterprise can be found in the continuous process industries (such as pharmaceutical, chemical, food, and metal processing) where minimization of resource consumption and energy efficiency is a critical performance indicator. In particular, adapting energy demand and supply could result in major economies.

3. Key challenges in manufacturing IT

Over the last decades, manufacturing companies have been implementing point solutions, each introducing a specific feature or fixing a certain issue, without regard to wider implications. As a result, many companies demonstrate a highly heterogeneous manufacturing ICT landscape. While these ICT landscapes are already costly to administer, addition of further capabilities becomes even more costly because these have to be fitted into the pre-existing heterogeneous landscape.

Cost is a main reason why the majority of manufacturing companies are usually well behind the latest manufacturing ICT technology. It is usually not the *unavailability* of technology that poses a bottle-neck for ICT innovation in manufacturing companies, but rather the fact that the latest manufacturing ICT technologies are, in effect, out of reach for most manufacturing companies, especially SMEs, due to the very high implementation costs. Other reasons are complexity and lack of capacity/ICT expertise – again due to the very high implementation costs. Without concerted action to overcome these challenges, or lessen their impact, adoption of manufacturing ICT innovation will always be doomed to make slow progress.

Manufacturing companies are increasingly facing the challenge to be flexible and offer highly customized products. Furthermore, manufacturing companies, especially SMEs, are confronted with ever stricter requirements from larger buyers, e.g. for tracking and tracing capabilities, or resource efficiency information. All these challenges can be expected to intensify in the future.

Manufacturing ICT solutions need to be available to support manufacturing companies, especially SMEs, in responding to these challenges successfully and without daunting implementation costs, thereby maintaining and boosting their competitiveness locally and in the increasingly globalized markets in which they operate.

In the next section, we recommend research areas that target these and related challenges. In describing each of these research recommendations further detail is given about the particular challenges that provide its rationale.

4. Research recommendations

The following research areas have been identified by the Road4FAME project as being key for supporting the future manufacturing scenarios presented:

a) Real-time data acquisition and analysis
b) Network-centric communication and collaboration between organisations, humans and systems across the entire value chain
c) Scalable cyber-physical system architectures for adaptive and smart manufacturing systems
d) A number of cross-cutting and non-functional challenges have also been identified and research into the following areas is recommended:
    i. Interoperability standards
    ii. Semantic mechanisms
    iii. Data visualization
    iv. Sociotechnical issues
    v. Training and education
    vi. Cybersecurity

Below, the rationale behind each recommendation is outlined, including details of the challenges to be addressed.

a) Real time data acquisition and analysis

Within manufacturing there is a continuous drive for efficiency and quality. Digitisation will not only enable communication between all partners in the value chain: digitisation of, for example, product quality, user-characteristics and more sophisticated production parameters based on advanced sensory systems will also be crucial to new innovations in the production process, products and services.

Underlying this is a need for improved situational awareness throughout the factory and the supply chain. This can only be achieved via much greater levels of data acquisition throughout the process and the use of this data for optimization, decision support and distributed control.

Here there is an important opportunity for the introduction of novel, easy to install, low-cost, sensor technologies and monitoring concepts. If wireless monitoring is to be used there is also a need for ultra-low power electronics and energy harvesting technologies, to avoid the need for battery change and associated maintenance costs.

An increase in data gathering will also require robust wired and wireless communication protocols that can deal with efficient transmission of data from a multitude of sensors and data streaming at high data rates, e.g. for vibration and video monitoring.

A future challenge will be the (physical) system integration of highly complex data acquisition systems and management of the data deluge from the myriad of sensors installed throughout the plant and the fusion of this with other information sources within the factory and supply chain. Here there is a need for visualization tools to manage the complexity of the data produced, allowing managers to understand the 'real world in real time', manage risk and make informed decisions on how to control and optimize the manufacturing process.

b) Network-centric communication and collaboration between organisations, humans and systems across the entire value chain

Three main forces are driving the distribution of manufacturing and flexibility of production networks: globalization, companies increasingly focusing on their core business, and decreasing lot sizes. In response, companies are increasingly required to establish and reconfigure their production networks faster and more flexibly in order to maintain their competitiveness. In order to achieve this, organisations, people, and systems have to communicate, share information in real time and collaborate seamlessly across value chains.

Diverse production systems link companies in networks, requiring of each company an active input in communication and organisation of the work of other organisations in the network. Individual industrialists have to shift their focus more and more to the added value of their offerings or the network as a whole. Cloud services are promising technologies for organising information throughout the value chain; already giving some companies direct access to logistics information from other organisations. This approach should be extended to information about manufacturing, enabling active inter-company synchronization of production data, process information and parts delivery. As a result, organisations will become more interdependent and compete together as almost a single entity.

In particular, relevant infrastructures and platforms have to be established which provide interoperability throughout supply networks at business and system level with regard to syntax and semantics (protocols). ICT security, solutions for intellectual property protection and the establishment of trust in collaborative cloud infrastructures are needed to ensure viability and acceptance by the manufacturing sector of those infrastructures and platforms.

Another important aspect is the definition of collaboration models. This goes beyond merely providing communication and protocols. Regulations, governance, advanced supply chain decision support and global optimisation, including mechanisms to ensure fairness to all parties, should also be considered.

c) Scalable CPS architectures for adaptive and smart manufacturing systems

Future ICT tools and technologies will give companies multiple opportunities, such as increases in efficiency and quality throughout value chains, the exploitation of additional markets, and manufacturing that is highly responsive to changing market and customer demands. Smart manufacturing will exploit advances in wireless sensor technologies, machine-to-machine (M2M) communication and ubiquitous computing, that would allow track-and-trace and monitor each individual stage of the production.

Together, an internet-style network of interconnected, intelligent machines are termed cyber-physical systems, which, according to the *Industry 4.0 glossary of the VDI committee for industry 4.0,*[ix] is a system which interlinks real (physical) objects and processes with information processing (virtual/cyber) objects and processes by means of open and distributed networks. Additionally, a CPS can use local or remote available services, or provide human-machine interaction. When CPS are networked, they are especially likely to demonstrate additional features such as dynamic reconfiguration (current example: in air traffic control), continuous evolution, partial autonomy (such as in local energy generation), and emerging behaviour (e.g. power supply oscillation).[x]

Figure 2 illustrates stages of development in CPS capability.

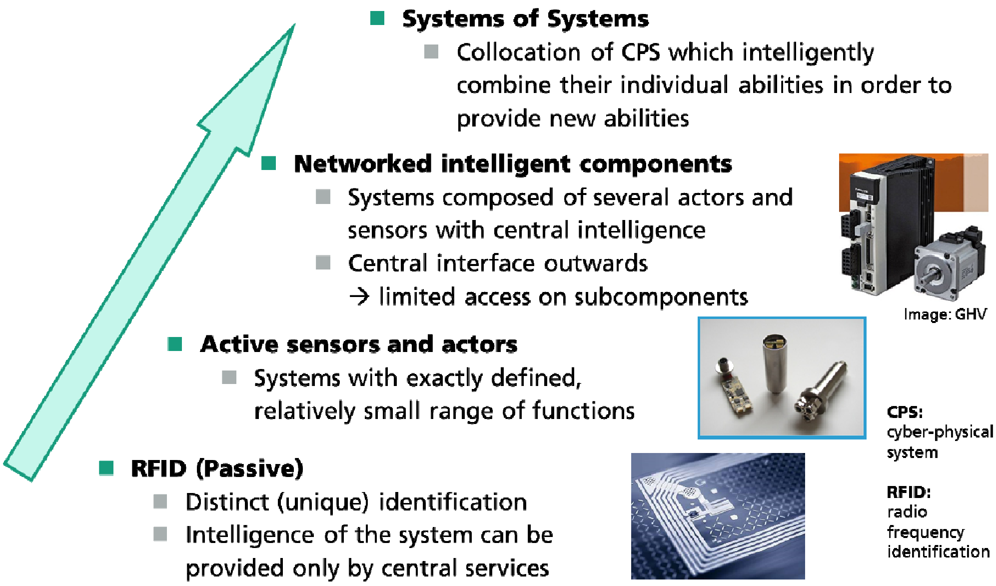

Figure 2 CPS Stages of Intelligence (© Fraunhofer IPA)

CPS will provide a shared situational awareness to support network-centric production by closing the loop between the virtual world and the physical world. In order to exploit the full potential of CPS, various existing ICT systems have to be integrated, adapted to the industrial needs, and deployed on the shop floor:

- Software systems such as computer-aided technologies, product lifecycle management, enterprise resource planning and manufacturing execution systems (known as CAx, PLM, ERP and MES respectively). Nowadays, integration of such systems is accompanied by considerable efforts at customization: configuration and implementation of interfaces which enable the necessary data exchange. However, to achieve integration and faster migration to new systems or features, architectures are required which enable seamless integration, for example by supporting information integration through industrial data standards and agreed ontologies rather than system integration. New architectures should also consider closed loops, for example to enable lifecycle-related optimization.

- Automation systems throughout all layers from sensor level, to IoT and CPS level, as well as machine controls, MES and ERP systems. Currently, integration of those systems usually takes place hierarchically, often via proprietary or industry-specific protocols and data formats. Hence, extensive effort is required to integrate or reconfigure automation systems. To overcome this issue, advanced architectures are required which enable seamless integration and low-effort (re-)configuration of systems throughout all layers (including the software systems described above), as well as direct communication among intelligent components as it is required, e.g. for distributed system components.

For both of these integration/migration challenges, appropriate ICT architectures have to be developed and implemented – including migration from existing ones. In so doing, aspects to be considered include:

- real-time capabilities
- interoperability among systems and components
- adaption (e.g. to varying governance structures)
- scalability (i.e. number of systems/components integrated)
- flexibility (i.e. types of systems/components to be integrated)

Some candidate approaches for achieving this are: 1. solutions based on M2M technologies; 2. service-orientation information and automation integration; and 3. cloud paradigms and infrastructures.

The convergence of cloud and IoT technologies will facilitate the development factories of the future. These future manufacturing plants will comprise numerous devices, physical and virtual smart objects, internally and externally interconnected, to dynamically enable configuration and monitoring of the operational capabilities of the plant, or networks of plants, quality control and efficiency improvement. Additionally, the traditional, fragmented processes of design, production and customer fulfilment will be replaced by a close-loop management of the end-to-end design-to-customer fulfil, where cycles are shorter and products are designed based on customer requirements (customer-focused manufacturing[xi]). Here, the processes do not finish with product delivery; the product-service provides information for the maintenance services and for continuous design of products and processes. The sensors in machinery and manufacturing services developed will facilitate the operational performance model for predictive maintenance of the machinery.

A global plant floor requires that the network of production facilities operates as a single virtual plant. Operations require individual plants' centralization control capabilities based on real-time information, multi-plant manufacturing execution systems (MMES) and major integration and visibility on supply-customer ecosystems based on enterprise manufacturing intelligence (EMI) platforms. Additionally, increased control and supervision requires the improvement and acceleration of decision-making capabilities based on real-time information, interoperability between systems and collaborative decision making. This environment requires adaptive and scalable architectures to support real-time data for operational management, supply-chain execution and collaborative decision-making. Scalable and multi-enterprise architectures are needed for: managing the operations of networks of organizations in the same supply chain; connecting MES and business processes in real time; establishing new business models based on secure cloud services.

d) Cross cutting and non-functional research recommendations

In addition to the three main research areas highlighted above, Road4FAME work has identified a number of cross-cutting and non-functional challenges that also need to be addressed across the board.

i. Interoperability standards

Interoperability standards covering protocols, syntax, and semantics are necessary to interconnect various systems across all levels. This would enable fast and faultless integration of CPS and manufacturing ICT systems both horizontally, (such as various partners in a production network) and also vertically (i.e., from the sensors and equipment to the supply chain management system) thus allowing fast reaction to changing commercial demands and conditions. We therefore recommend that the EC funds Co-ordination and Support Actions concerned with:

- Supporting the definition and harmonization of system-of-systems integration standards (i.e. for the manufacturing domain), considering vertical and horizontal integration aspects
- Supporting the creation of guidelines for fast adoption of the developed interoperability standards and their integration with business processes
- Supporting the set-up of consistent evaluation environments showing the benefits of the newly defined/harmonized standards
- Supporting and monitoring the implementation of strategies for standard-roll-out and development, to ensure that standards are accepted by industry and applicants (e.g. due to reduced complexity, coverage of domain-specific requirements, acceptance and implementation by key players, etc.)

ii. Semantic mechanisms

Beyond standards, semantic mechanisms are needed which enable easy exchange of information and data integration of legacy systems and systems from different industrial domains (since standards are mostly sector-specific). Semantic technologies such as ontologies for data acquisition, knowledge elicitation and information exchange have to support the mapping of information representation throughout different systems and domains. In addition, research is required into self-descriptions of CPS/components/systems to provide information on capabilities and access information for interfaces.

iii. Data visualization

Data visualization is necessary to deal with complexity and to support human decisions. Here there are requirements for appropriate visualization methodologies for large amounts of information (filtering, etc.) and to extract potential relationships. Additionally, there is a need for role-based/user-specific views to present the most appropriate and relevant information to users.

iv. Sociotechnical issues

Addressing sociotechnical issues is a major factor in successful deployment of new technologies. A key element of this is the HMI, the primary interface between humans and the system. The objective is to provide HMIs that are intuitive to use and modular so that they can be configured to support application- and task-specific user interfaces.

v. Training and education

Training and education is an important underpinning activity. This needs to address decision makers, the engineers who are developing and deploying systems, and end users, in order to achieve an awareness and acceptance of new technologies.

vi. Cybersecurity

Cybersecurity[xii], in particular, represents a critical and complex cross-cutting challenge. According to Microsoft:

> '…business value is found in more connected systems – and is increased when more data is available to be analyzed – making security more difficult and costly. The more devices connecting to a system, the more vulnerable that system becomes. Data security is also more complicated with more systems using the same data source for different types of analytics, yet each system has its own unique vulnerabilities and consumes data differently.'[xiii]

As the IoT expands, cybersecurity will have to be considered at every point, and common, sector-specific threats will need to be identified. Security requirements that are unique to CPS will have to be determined. A risk management framework and methodology to enable, assess, and assure cybersecurity for adaptive and smart manufacturing systems will have to be established; adaptable computational and storage tools including methods for protection and security of intellectual property will have to be identified, developed, and deployed. Novel information security concepts and/or approaches, such as turning properly constructed interfaces from attack surfaces[xiv] into cyber-defense surfaces, offering explicit and implicit design guarantees, [xv] and providing security as a class of interface guarantee, will have to be explored. It will be much more effective and ultimately cheaper to secure smart manufacturing systems at the engineering design phase,[xvi] rather than later. The economic and technical viability of possible integration with legacy systems as well as existing open source applications and tools will also have to be assessed.

5. Potential impact for manufacturing industry

If the challenges outlined in the previous sections are successfully addressed the expectation is that the research would contribute to enabling the following capabilities:

- **Novel approaches to providing manufacturing ICT capabilities swiftly and at low implementation cost so that new functionality can be incorporated if, when and as needed**: To achieve this, the heterogeneity of the existing ICT landscape in manufacturing companies must be successfully addressed. (Some keywords in this regard are: interoperability solutions, semantic interfaces, abstraction layers, modularity/apps/out-of-the-box solutions/plug-and-play, migration strategies)
- **Enabling flexibility at factory level and across supply chains**: Semantic technologies and self-learning capabilities to support re-configurability at shop-floor level; seamless integration across the supply chain to guarantee quick adaptation to new customization of products
- **Enabling traceability**: Approaches should be investigated to provide tracking/tracing capabilities even for manufacturers which do not manufacture at a high level of automation. (Some keywords in this regard are: retrofitting, robust self-powered wireless sensors)
- **Enabling optimization of resource efficiency, decision making, predictive maintenance**: Approaches should be investigated to introduce and operate monitoring infrastructures with a very large number of sensors. (Some keywords in this regard are: connectivity, data acquisition, integration with decision making applications, data fusion, real-time data processing, real-time decision making)

The direct impact of these improved capabilities would be to provide **financial benefits** to manufacturing companies through:

- Accelerated deployment of ICT innovation in manufacturing companies by making manufacturing ICT innovation not only available but also accessible for manufacturing companies, especially SMEs, by means of **drastically reduced implementation costs**
- **Increased competitiveness** of smaller and medium sized manufacturing companies through the availability of out-of-the-box ICT solutions , enabling them to be more flexible, offer higher degrees of customization and respond successfully to the increasing demands for tracking and tracing capabilities or resource efficiency
- Transfer of solutions from the wider ICT domain to the manufacturing domain, cross-fertilizing the manufacturing domain with ICT solutions from other fields and thus **reducing development and implementation costs**

Glossary of acronyms

CaX	computer-aided technology
CNC	computer numerical control
CPS	cyber-physical system
EFFRA	European Factories of the Future Research Association
ERP	enterprise resource planning
HVM	high value manufacturing
HMI	human–machine interface
ICT	information and communications technology
Industry 4.0	German government and industry initiative to promote digital manufacturing
IoT	Internet of Things
MES	manufacturing execution system
M2M	machine-to-machine
NDT	non-destructive testing
OEM	original equipment manufacturer
SME	small and medium-sized enterprises
TSB	Technology Strategy Board
VC	venture capital

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[viii] http://www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/Manufacturing/dttl_2013%20Global%20Manufacturing%20Competitiveness%20Index_11_15_12.pdf

[ix] http://www.iosb.fraunhofer.de/servlet/is/48960/Begriffsdefinitionen%20des%20VDI%20GMA%20FA7%2021.pdf?command=downloadContent&filename=Begriffsdefinitionen%20des%20VDI%20GMA%20FA7%2021.pdf

[x] http://www.cpsos.eu/wp-content/uploads/2014/09/CPSoS-flyer.pdf

[xi] European Union (2013). *Factories of the Future* http://www.effra.eu/attachments/article/129/Factories%20of%20the%20Future%202020%20Roadmap.pdf

[xii] Within the context of manufacturing scenarios, cyber security is defined as 'the protection of information (on computers and networks) against unauthorized disclosure, transfer, modification, or destruction' by SMLC (http://smartmanufacturingcoalition.org).

[xiii] http://www.microsoft.com/windowsembedded/en-us/intelligent-systems.aspx

[xiv] https://en.wikipedia.org/wiki/Attack_surface

[xv] https://en.wikipedia.org/wiki/Design_by_contract

[xvi] "Sicherheitskonzepte für Industrie 4.0 können nicht im Nachgang eingeflickt werden, sondern müssen schon bei der Gestaltung der Gesamtlösung im Sinne des Security by Design berücksichtigt werden." Security-Anforderungen für Industrie 4.0 http://www.konstruktion.de/themen/antriebstechnik/security-anforderungen-fur-industrie-4-0/